

11 W narrow linewidth laser source at 780nm for laser cooling and manipulation of Rubidium

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Abstract: We present a narrow linewidth continuous laser source with over 11 W output power at 780 nm, based on single-pass frequency doubling of an amplified 1560 nm fibre laser with 36% efficiency. This source offers a combination of high power, simplicity, mode quality and stability. Without any active stabilization, the linewidth is measured to be below 10 kHz. The fibre seed is tunable over 60 GHz, which allows access to the D₂ transitions in ⁸⁷Rb and ⁸⁵Rb, providing a viable high-power source for laser cooling as well as for large-momentum-transfer beamsplitters in atom interferometry. Sources of this type will pave the way for a new generation of high flux, high duty-cycle degenerate quantum gas experiments.

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1. Introduction

The rapid progress of atomic physics over the past few decades has largely hinged upon the development of high power, narrow linewidth laser sources for manipulating and probing atoms. Increased laser power allows for higher flux and collection efficiency in magneto-optical traps [1], as well as further improvements in lattice-based cooling techniques [2]. In atom interferometry, narrow linewidth, high power near-resonant lasers are a prerequisite to achieving higher sensitivities with large-momentum-transfer beamsplitting [3, 4, 5].

The most common atomic species used for making alkali gas Bose-Einstein condensates (BECs) is ^{87}Rb . This is due in part to its excellent scattering properties which allow efficient evaporative cooling, but also because of the availability of inexpensive 780nm CD burner laser diode sources which can be stabilized using an external cavity grating [6, 7]. Today, for a modest cost, a grating stabilised diode master laser/tapered amplifier configuration will produce a cw source with a 10's of kHz linewidth and up to 2 W of output power. However, the spatial mode quality is typically poor, leading to usable powers of < 500 mW after spatial filtering. These power levels and linewidths are not adequate for next generation high flux Rb BEC and interferometers and thus an alternate approach is required.

In recent years a great deal of effort has focused on the development of high power narrow linewidth CW sources at 589 nm primarily for sodium guide star applications, but also for laser cooling. Currently doubling raman fibre lasers in an external resonant cavity have demonstrated powers of 50W [8] and doubling efficiencies of 86% at 25W [9]. Another approach by Chiow et al. used a modified Coherent 899 Ti:sapphire laser to achieve 6W of light at 852 nm by injection locking. Frequency stabilization to a high-finesse optical cavity resulted in a linewidth of < 1 kHz [10]. This technology allowed for efficient high-order Bragg diffraction in the largest area atom interferometer produced to date [11]. Diode pumped alkali vapour lasers have now demonstrated 48W in Cs [12].

At the 780nm Rb wavelength, tunable Ti:sapphire and Alexandrite lasers have demonstrated up to 6W, offering the option of injection locking [13]. Zweiback *et. al* have demonstrated 28W from a diode pumped alkali vapour laser [14]. By cascading two PPLN crystals, Thompson et al. were able to obtain 20% SHG efficiency and generate 900mW of light at 780 nm [15]. Recently the atomic physics community has also begun to investigate the possibility of using compact cw frequency-doubled sources for portable atom interferometry based sensors [16, 17].

In this paper we present a compelling argument to move to a doubled laser system in atomic physics labs working with Rubidium. We have produced a 11.4W cw laser at 780.24 nm with a 6 kHz linewidth by single-pass frequency doubling in a single PPLN crystal. The doubling

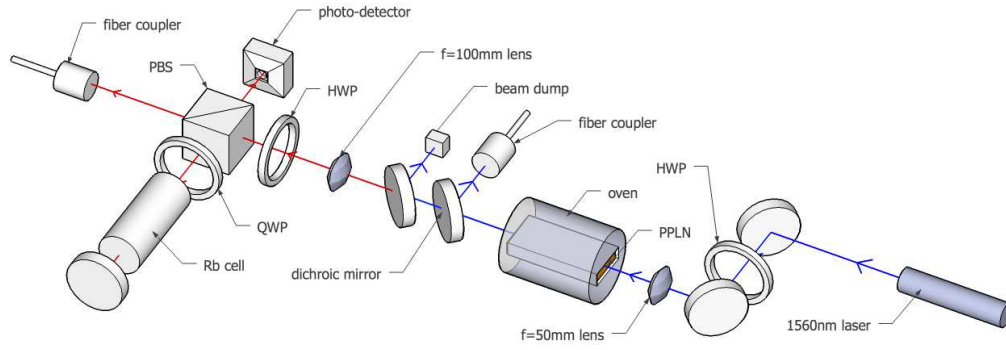


Fig. 1. Schematic of the experimental setup. The seed and fiber amplifier are not shown in the diagram. PPLN - periodically-poled lithium niobate crystal, HWP - half-wave plate, QWP - quarter-wave plate, PBS - polarizing beamsplitter. After the oven, the 780nm and 1560nm light are separated by the dichroic mirrors.

efficiency is 36%. The setup is simple and robust, relying on a narrow-linewidth fiber laser [18] to provide a highly stable seed, and a low noise 30 W fibre amplifier [19] to generate the high powers required for efficient doubling.

2. Apparatus

The experimental setup is shown in Figure 1. The source is an amplified NP Photonics Rock fibre laser with a centre wavelength of 1560.48 nm and a tuning range of ± 30 GHz. Only ± 150 MHz tuning is readily available via piezo control, otherwise the laser must be tuned with temperature. This laser has a specified linewidth of < 5 kHz integrated over 100 ms. The output frequency appears nearly insensitive to acoustic noise, particularly compared to an external cavity diode laser. We do observe a slow thermal drift of the seed laser, which is easily counteracted by a low bandwidth servo loop with an error signal provided by saturation spectroscopy of Rubidium with the doubled light. The 1560.48 nm seed is amplified by an IPG Photonics fiber amplifier with a maximum output power of 30 W. The amplified beam has a $1/e^2$ diameter of 1.1 mm and is linearly polarized.

Using a single plano-convex lens with a 50 mm focal length, this beam is focused into the centre of a 40 mm long periodically-poled lithium niobate (PPLN) crystal. The crystal is 1 mm thick and has five 1 mm wide gratings, each with a different domain period [20]. In this work we have used a grating with a $19.5 \mu\text{m}$ domain period. The crystal is housed inside a temperature-stabilized oven on a three-axis translation stage, and held at 81.60°C for optimal phase matching. The polarisation of the light incident on the crystal is controlled using a $\lambda/2$ waveplate, which is optimized to achieve maximum doubling efficiency.

The linearly polarised 780 nm light exiting the crystal is filtered by two dichroic mirrors and collimated with a 100 mm lens. This light is analyzed via saturated absorption spectroscopy using rubidium vapor, which also provides the locking signal for the seed laser (a fibre modulator is used to generate the necessary frequency sidebands for locking). The remaining 1560 nm light reflected by the dichroic mirrors can be used for dipole trapping. The optical setup is robust and compact, and does not require any active control of the optical components, with the exception of temperature-stabilizing the PPLN crystal.

3. Results

The power in the second harmonic is plotted as a function of input power in Figure 2. A maximum efficiency of 36% is achieved, giving 11.4 W of output power at 780 nm. These data were taken without any adjustment of the crystal temperature or alignment. This efficiency compares very favourably with more complex and lower power cavity-enhanced doubling systems at these wavelengths [21]. The inset in Figure 2 shows the spatial mode of the 780 nm light, after collimation from the doubler. By tuning the seed laser temperature and piezo, we can scan through all of the rubidium D₂ transitions without a noticeable change in power.

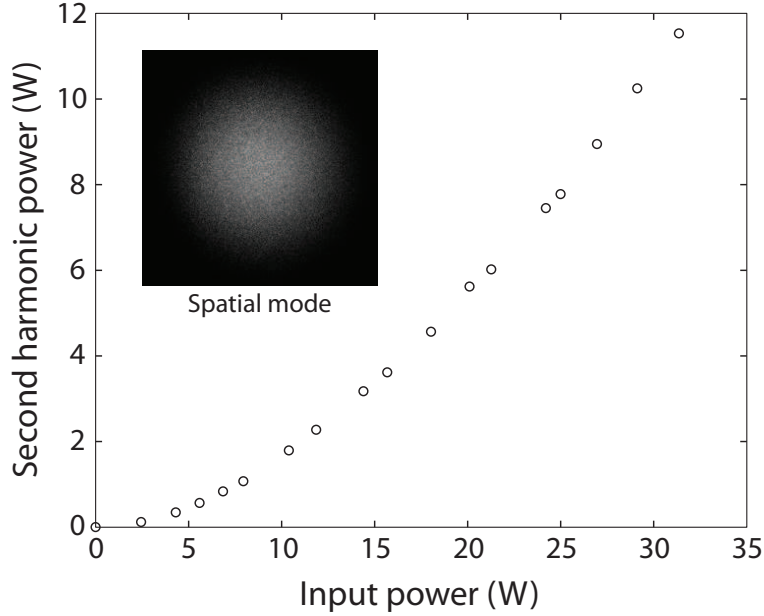


Fig. 2. Measured second harmonic power as a function of input power from a single 40 mm PPLN crystal. The maximum output power is 11.4 Watts at 780 nm. The inset shows the spatial mode of the output.

To measure the linewidth of the 780 nm beam, a small portion of output power is directed through a fiber-coupled electro-optic phase modulator (modulation frequency 50 MHz) and then into an acoustically isolated unequal path length Mach-Zehnder interferometer. One arm of the interferometer is passed through a 10 m single-mode optical fibre, giving a fringe spacing of 21 MHz. The output of the interferometer is monitored on a fast photodetector, and demodulation and low-pass filtering is used to generate an error signal which can be straightforwardly calibrated to the fringe spacing. The frequency noise spectrum obtained at the zero-crossing of the error signal is given in Figure 3. Above 10 kHz, the measurement is limited by detector and electronic noise, aside from a peak at 500 kHz which corresponds to a noise feature in the seed laser. By integrating the noise spectrum over the range plotted in Figure 3, we determine the linewidth of the frequency-doubled light to be 6 kHz over 100 ms, which is comparable to that of the NPP seed laser specified as < 5 kHz.

4. Conclusion

We have presented a frequency-doubled laser source at 780 nm, which provides over 11 W of continuous power in a high quality Gaussian mode with a linewidth of 6 kHz integrated over

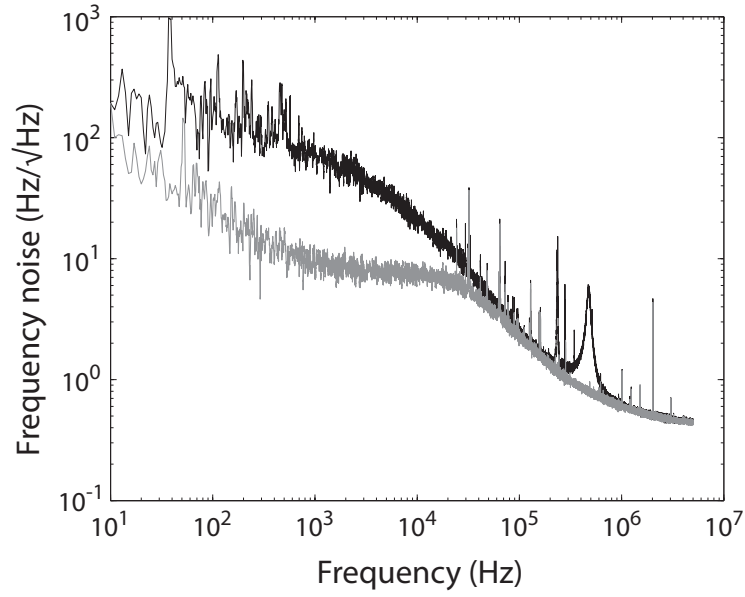


Fig. 3. Frequency noise spectrum measured using an unequal path length Mach-Zehnder interferometer as described in the text. The gray curve shows the detector noise. Integrating from 10 Hz to 5 MHz gives a linewidth of 6 kHz.

100ms. We believe this to be the highest reported power at this wavelength. The system does not require locking to a high finesse cavity or using multiple crystals as in previous efficient frequency doubling experiments, which makes the apparatus robust and remarkably simple to set up. This system has applications in a variety of atomic physics experiments, including for high-order Bragg diffraction in precision atom interferometry.

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